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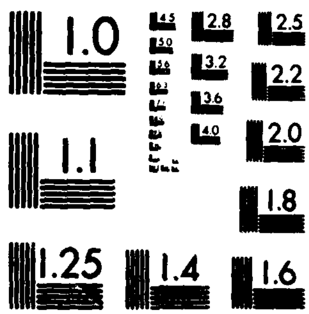

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In this technical note we compare both qualitatively and quantatively, the two methods (AT&T and DCA's) being used to perform access line engineering on the current AUTOVON network. The DCA method was found to be superior but had one deficiency. We then present a method which overcomes this deficiency and performs better than the other two.

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TECHNICAL NOTE NO. 22-81

AN INVESTIGATION OF ACCESS AREA ENGINEERING METHODS FOR AUTOVON

AUGUST 1981

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Approved for Publication

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FOREWORD

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EXECUTIVE SUMMARY

In this technical note we compare both qualitatively and quantatively, the two methods (AT&T and DCA's) being used to perform access line engineering on the current AUTOVON network. The DCA method was found to be superior but had one deficiency. We then present a method which overcomes this deficiency and performs better than the other two.

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I. INTRODUCTION

In a letter [1], the Traffic Engineering and Analysis branch of the Defense Communications Agency requested our help in standardizing the access line engineering methods. Up to now there have been two methods which have been jointly used in engineering the access area of AUTOVON. One of these methods was developed by the Traffic Engineering and Analysis Branch of DCA Headquarters and the other by AT&T Longlines. It turns out that both methods when applied to the same access area produce widely different results. In this Technical Note we examine these methods in great detail and present a new method which seems to be more accurate than either existing method.

The basic configuration of a typical AUTOVON access area in the Defense Communications System (DCS) is shown in Figure 1. Calls trying to go from an AUTOVON switch to a PBX are referred to as IN calls. Calls trying to go from the PBX to the AUTOVON switch are referred to as OUT calls. The IN calls first attempt to seize an IN only trunk; if all of those trunks are busy it then tries to seize a two-way trunk. If it is blocked on both, the call is lost. The OUT calls are only allowed to use the two-way trunks. Under this arrangement, the IN calls have accessibility to more trunks than the OUT and in general see a better grade of service. The reason for this type of configuration is to get the traffic off the network.

At the AUTOVON switch, numerous peg counts on traffic statistics are taken over given periods of time. These peg counts are then used in the Access Line Engineering (ALE) process. This process comprises three basic steps:

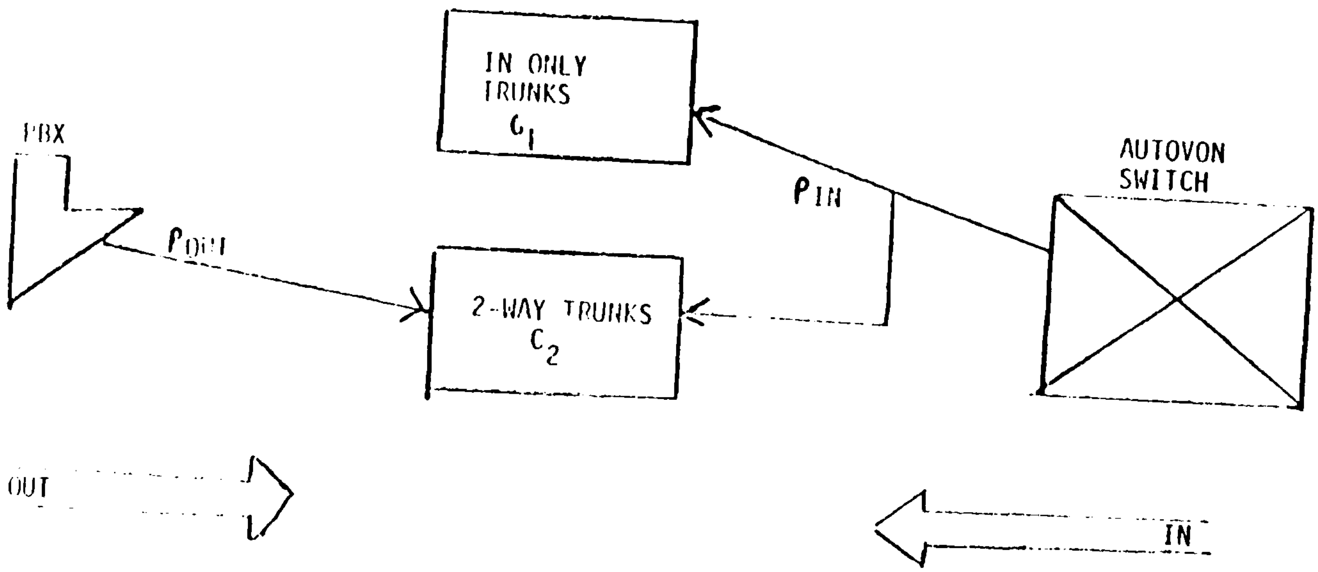

Figure 1. Typical DCS Access Area Configuration

1. Load Determination

2. Retry Adjustment

3. Sizing .

In the load determination step, (see Figure 1) the peg count information is used to determine the IN-ward offered load, denoted by ρ_{IN}, and the OUT-ward offered load, denoted by ρ_{OUT}. This step is the most critical of the three, because the remainder of the process is only as accurate as the accuracy of ρ_{IN} and ρ_{OUT}. If the particular method misses the actual values of ρ_{IN} and ρ_{OUT}, the remaining two steps in the ALE process are meaningless.

Once the offered loads have been determined, they must be reduced to account for retries, i.e., calls that were blocked and are trying again. This is accomplished in step 2 of the ALE process, retry adjustment. The retry adjustment step consists of selecting a set of constants from empirical tables and then performing some simple additions and multiplications.

The final step in this process is sizing. There are two grades of service (GOS) in this system: the INGOS, denoted by PB_1, and the OUTGOS, denoted by PB_2. The INGOS is the blocking probability that the IN traffic is seeing and the OUTGOS is the blocking the OUT traffic sees. The sizing

step involves determining the number of IN only channels, denoted by C_1^*, and two-way channels, denoted by C_2^*, that will achieve a desired IN and OUTGOS, denoted by PB_1^* and PB_2^*. The current values of PB_1^* and PB_2^* are .05 and .10; that is, 5% of the IN calls and 10% of the OUT calls are lost.

In section II of this Technical Note, we describe the ALE methods used by the Traffic Engineering and Analysis Branch of DCA Headquarters and those of AT&T Longlines. The ALE method we have developed is given in section III. Section IV contains an analysis and comparison of all three methods. Finally, some conclusions are given in section V.

II. THE TWO CURRENT ALE METHODS

In this section, the two ALE methods currently being used to engineer the access area are described. Before we get into the specifics of each method, the peg count information collected at the switch is discussed. Figure 2 is an example of the type of peg count information that is collected by the switch.

	LINE USAGE (CCS)	PEG COUNT IN (PCI)	PEG COUNT OUT (PCO)	
IN	766	737	N/A	$C_1=23$
TWO-WAY	1406	282	992	$C_2=41$
OVERFLOW	N/A	147	N/A	

Figure 2. Traffic Data Collected at the Switch

The last column represents the current configuration of the access area. There are 23 ($=C_1$) IN only lines and 41 ($=C_2$) two-way lines. The first column [LINE USAGE] gives the carried traffic in terms of CCS (100 call seconds) for the IN only trunks and the two-way trunks. Since only IN calls are allowed to use the IN only lines, the 766 CCSare all carried IN traffic on

these lines. Both types of traffic can use the two-way lines and so the 1406 CCS comprises both carried IN and OUT traffic. By carried traffic, we mean traffic that has already seized the lines.

The second and third columns indicate the number of calls during the sampling time. The second column deals only with the IN traffic. The 737 is the number of IN attempts on the IN only lines. Of these, 282 were blocked and tried to use the two-way lines. Of those 282, 147 were blocked and overflowed the system, i.e., did not receive service. Thus, 737 and 282 are the number of IN attempts that were offered to the IN only and two-way lines respectively. These numbers represent the offered type of traffic, and not carried traffic as in the first column. However the number of attempts carried on the IN lines can be found by subtracting 282 from 737; i.e., 737-282=455.

The number 992 in the third column is the number of carried OUT attempts on the two-way lines. It is not the number of offered OUT attempts. This peg count information, along with the number of IN and OUT lines, is all of the information available to perform the ALE process. Using these numbers, the DCA and AT&T methods of access line engineering can now be described.

1. THE DCA METHOD

a. Load Determination. From the second column, the INGOS and OUTGOS can be computed via:

$$\text{INGOS} = 147/727 = .20$$

$$\text{OUTGOS} = 147/282 = .52. \qquad (1)$$

For the IN traffic, .20 is the actual grade of service. The computation for the OUTGOS in equation (1) is actually the blocking the IN traffic sees on the two-way lines. DCA assumes that this blocking probability equals the OUTGOS. This assumption is false, for a theoretical reason see [2] and [3]. Basically, the problem stems from the fact the overflow process from the IN lines is peaked and tends to be clustered. So the IN customers who are blocked on the IN only lines and overflow to the two-way lines tend to be closer together and see a higher blocking than the OUT customers who arrive more regularily in time. Thus, the .52 is a high estimate of the grade of service for the OUT customers.

As we pointed out in the first part of this section, the usage numbers are carried traffic in terms of CCS's. Next, DCA develops a percentage for each type of traffic using columns 2 and 3 of Figure 2:

$$\%\ \text{IN traffic on 2-way} = {}^{282}/(282+992) = 22\% \qquad (2)$$

$$\%\ \text{OUT traffic on 2-way} = 100-22 = 78\%.$$

The only problem here is that 282 is the number of offered IN attempts to the two-way lines and the 992 is carried OUT attempts. Probably, for most applications this is not a serious error.

Using these percentages, the carried IN and OUT traffic can be found as

Carried IN = 766+.22(1406) = 1077 CCS (3)

Carried OUT = .78(1406) = 1095 CCS.

By dividing these numbers by the completion rates (i.e., 1-GOS), we get the offered IN and OUT loads as

IN Load = 1077/(1-.2) = 1346 CCS (4)

OUT Load = 1095/(1-.52) = 2281 CCS.

b. Retry Adjustment. To account for retrials, a percentage of the difference between the carried load and the offered load is added to the carried load to obtain the first attempt offered load. For the IN traffic this percentage is 35%; for the OUT traffic it is 45%. Performing these calculations we get

IN offered Load = 1077+.35(1346-1077) = 1171 CCS (5)

OUT offered Load = 1095+.45(2281-1095) = 1629 CCS.

There is one last adjustment to make if the desired GOS in the sizing step is greater than .05. This adjustment is based on the empirical data given in Table I.

TABLE I. ADJUSTMENT FACTORS BASED ON DESIRED GOS

SIZING GOS	MULTIPLICATION CONSTANT
.0-.1	1.00
.1-.15	1.06
.15-.2	1.09
.2-.25	1.125
.25-1.00	1.16

In the sizing step we will determine the number of IN lines and two-way lines to give a .05 INGOS and a .10 OUTGOS. Using Table I, we now adjust the OUT offered load by 1.06 to give

$$\text{OUT offered load} = 1629(1.06) = 1727 \text{ CCS.} \quad (6)$$

b. Sizing. In this step, we wish determine the number of IN only channels (C_1^*) and two-way channels (C_2^*) required to achieve an INGOS = .05(PB_1^*) and an OUTGOS = .10(PB_2^*). Obviously, there are several combinations of C_1^* and C_2^* that will achieve the desired GOS's. DCA's sizing philosophy is to size the IN channels to a GOS equal to PB_1^*/PB_2^* (=.5 in our example) and then size the OUT channels to PB_2^*. Simple multiplication then gives the desired INGOS. The fallacy in this approach is that the amounts of blocking the IN and OUT traffic see on the two-way lines are not equal.

Using Erlang B tables (see [4] for example), for an offered load of 1171 CCS, we find the number of channels required to give a .50 GOS on the IN only lines; therefore, $C_1^* = 17$. With this configuration, 1171(.5049) = 591 CCS overflows to the two-way trunks. The factor .5049 is the actual blocking when 1171 CCS are offered to 17 trunks. Next, we calculate the peakedness factor (PF) of the overflow process via the following formula:

$$\text{PF} = \text{Var of Overflow}/\text{Mean of Overflow} \tag{7}$$

where

$$\text{Mean of Overflow} = \frac{1171}{36}(.5049) = 32.53\ (.5049) = 16.42 \tag{8}$$

$$\text{Var of Overflow} = 16.42\ \left(1-16.42 + \frac{32.53}{17+1+16.42-32.53}\right). \tag{9}$$

We note that we have changed from CCS's to erlangs because most of the tables DCA uses for the remaining part of their ALE are in erlangs. Therefore, the peakedness factor, PF, is given by

$$\begin{aligned} \text{PF} &= 29.42/16.42 \\ &= 1.79. \end{aligned} \tag{10}$$

Some general formulas for the mean (α) and variance (ν) of the overflow process are

$$\alpha = \rho E_B(\rho, C)$$

$$\nu = \alpha \left[1-\alpha+ \frac{\rho}{C+1+\alpha-\rho}\right] \tag{11}$$

where $E_B(\rho,s)$ in Erlang's Loss Formula is given by

$$E_B(\rho,C) = \frac{\frac{\rho^C}{C!}}{\sum_{r=0}^{C} \frac{\rho^r}{r!}} \tag{12}$$

and ρ is the offered IN load and C is the number of IN only channels. The peakedness factor is given by

$$\begin{aligned} PF &= \nu / \alpha \\ &= 1-\alpha+ \frac{\rho}{C+1+\alpha-\rho} \quad . \end{aligned} \tag{13}$$

Returning to our example, we next calculate the offered load and weighted average peakedness factor for the load on the two-way lines. The offered load is given by:

$$591(1.79)+1727(1) = 2785 \text{ CCS}. \qquad (14)$$

The multiplicative constant (1) for the offered OUT traffic results from the fact that the OUT offered load is Poisson or smooth, and has a peakedness factor of 1, (see [3]). Next, we get the offered load to the two-way lines, 591+1727 = 2318 CCS, and divide this number into 2785 to get a peakedness factor for the two-way lines as

$$PF = 2785/2318 = 1.20.$$

The offered load to the two-way lines is then converted to erlangs by dividing by 36 to get 2318/36 = 64.4 erlangs offered. Wilkinson B Tables [5], is then used to determine C_2^*. Using those tables with PF = 1.20, blocking equal to .1 and offered load of 64.4 erlangs, gives $C_2^* = 66$.

Table II summarizes the results of applying DCA's ALE method to this particular access area. Note that the DCA's method would result in a change in the present line configuration from 23 IN lines and 41 OUT lines to 17 IN lines and 66 OUT lines, or 19 more lines. We further note that in the sizing step this method assumed the amounts of blocking that the IN and OUT traffic sees on the two-way lines are equal. As we pointed out earlier, this assumption is false.

TABLE II. SUMMARY OF THE DCA METHOD

STEP	RESULT
Load Determination	IN = 1346 CCS OUT = 2281 CCS
Retry Adjustment to Load	IN = 1171 CCS OUT = 1727 CCS
Sizing	$C_1^* = 17$ $C_2^* = 66$

2. THE AT&T METHOD

a. <u>Load Determination</u>.

Using the data given in Figure 2, the AT&T method first adds the usage on the IN and two-way lines to get the total usage:

$$\text{Total Usage} = 766+1406=2172 \text{ CCS.} \tag{15}$$

Next, this method adds the IN only and two-way lines to get the total number of lines:

Total Lines = 23+41 = 64 lines. (16)

Then, this method uses Erlang B tables to get the offered load that when offered to 64 trunks will give 2172 CCS carried; from the table one gets

Offered load = 2608 CCS. (17)

Returning to Figure 1, one sees that the IN traffic can use both the IN and two-way lines, whereas the OUT traffic only the two-way lines. The queueing system from which the Erlang B tables are derived assumes all the traffic uses all the lines. As such it appears that AT&T's method is not using the proper system to determine the offered load. In fact, their use of the Erlang B tables would probably result in lower offered loads.

Next AT&T develops a percentage for each type of traffic. Using the second and third columns of Figure 2, AT&T gets

$$\% \text{ of IN traffic} = \frac{737}{(737+992)} = 42\% \qquad (18)$$

$$\% \text{ of OUT traffic} = 100-42 = 58\%$$

With regard to these calculations, AT&T has the same inconsistency that the DCA method has: 737 was the number of offered attempts and 992 the carried attempts. These percentages (Eq. 18) are applied to the offered load given by equation (17) to get the offered load for each class of traffic,

$$\text{IN traffic} = .42(2608) = 1095 \text{ CCS}$$

$$\text{OUT traffic} = .58(2608) = 1513 \text{ CCS.} \quad (19)$$

b. Retry Adjustment.

As in the DCA method, this step involves the use of empirical tables. A percentage of the difference between the carried load and the offered load is added to the carried load. These empirical tables are given in Table III.

TABLE III. AT&T's EMPIRICAL TABLE FOR RETRIES

INGOS from	Use x % of Difference
0 - .10	100%
.1 - .2	75%
.2 - .3	50%
.3 - .4	35%
.4 - .5	30%
.5 - .75	20%
Greater Tnan .75	30%

Using the percentages developed in 2.a. the carried IN and OUT traffic is

$$\text{Carried IN traffic} = .42(2172) = 912 \text{ CCS}$$
$$\text{Carried OUT traffic} = .58(2172) = 1260 \text{ CCS.} \tag{20}$$

From the peg counts we get

$$\text{INGOS} = 147/737 = .20. \tag{21}$$

From Table III, this INGOS implies we use 75% of the difference between the offered and the carried traffic. Therefore, the results and loads are

$$\text{IN load} = 912+.75(1095-912) = 1049 \text{ CCS}$$
$$\text{OUT load} = 1260+.75(1513-1260) = 1450 \text{ CCS.} \tag{22}$$

c. Sizing. The AT&T sizing method is similar to DCA's except in how the IN only lines are sized; since the desired IN and OUT GOS (PB_1^* and PB_2^*) are .05 and .1, the AT&T method sizes the IN lines to be .2 and the two-way lines to be .1. We have not been able to explain how they feel that this practice will result in a .05 IN and a .1 OUT. It would appear that the INGOS is around .02.

Using Erlang B tables with an offered load of 1049 CCS, we find the number of IN lines to give a blocking of .2, or $C_1^* = 26$. The actual blocking via Erlang's Loss Formula is $E_B(1049/36,26) = E_3(29.139,26) =$

.204. This implies that 214 CCS overflow to the two-way lines and 835 CCS are carried on the IN lines. Using equation (13), the peakedness factor is 2.71. Next, we multiply the overflow 214 CCS from the IN lines by 2.71 to get the variance of the overflow. The total mean offered load to the two-way lines is 214+1450 = 1664 CCS. Since the OUT load is Poisson in nature and has a peakedness factor of 1, the variance of the offered load to the two-way is

$$\text{Variance of offered load} = 1450+214(2.71) = 2030 \text{ CCS}; \tag{23}$$

or an overall peakedness factor

$$PF = 2030/1664 = 1.22. \tag{24}$$

Next, we convert the offered load to erlangs, 1664/36 = 46.2 erlangs, and use Wilkinson tables for a .1 blocking at PF = 1.22 to find the required number of two-way channels to be $C_2^* = 48$. Again, as in the DCA method, this step assumed the IN and OUT traffic sees the same blocking on the two-way lines.

TABLE IV. SUMMARY OF THE DCA AND AT&T METHODS

STEP		DCA	AT&T
Load	IN	1346 CCS	1095 CCS
Determination	OUT	2281 CCS	1513 CCS
Retry	IN	1171 CCS	1049 CCS
Adjustment To Load	OUT	1727 CCS	1450 CCS
Sizing	C_1^*	17	26
	C_2^*	66	48

Table IV summarizes the results for both the DCA and AT&T methods. As we can see from this table, the AT&T method results in significantly lower loads than the DCA method. Because of these lower loads and the fact they size the IN lines to .2, AT&T also gets a significantly different access area configuration after sizing. It was because of such differences that we were asked to look into this problem. From our discussion so far, we can see that in the load determination sizing steps the DCA methods assume the

blockings on the two-way lines are equal; whereas the AT&T method uses an improper system in the load determination step and makes the same assumption about equal blocking in the sizing step. A method that gives better results is discussed in section III.

III. THE DCEC ACCESS LINE ENGINEERING METHOD

Since the DCA and AT&T methods gave such widely different answers, we decided to see how we would go about solving the ALE problem. Our method is not based on table assistance but is based on using a computer to make the appropriate calculations. Of course, we could develop some tables which one could use instead of a computer. Our method for the access line and peg count parameters given in Figure 2 is given below.

1. LOAD DETERMINATION

From Figure 2, the blocking IN traffic sees on the IN only lines is 282/737 = .383. Since there are 23 IN lines, we want to find the erlang load ρ such that

$$E_B(\rho, 23) = .383, \tag{25}$$

where $E_B(\rho,23)$ is Erlang's Loss Formula for 23 lines. The computer method used to solve this equation is based on Newton-Raphson's method [6]. This method is an iterative procedure where successive values of ρ, denoted by ρ_n, are computed based on previous values, until a convergence criterion is satisfied.

For this example the iteration formula is

$$\rho_{n+1} = \rho_n - \frac{E_B(\rho_n,23) - .383}{E_B(\rho_n,23)\left[\frac{23}{\rho_n} - 1+E_B(\rho_n,23)\right]}, \tag{26}$$

where $\rho_0 = 21$. For the general problem of finding ρ such that

$$E_B(\rho,C) = B_{IN}, \tag{27}$$

the iteration formula is

$$\rho_{n+1} = \rho_n - \frac{E_B(\rho_n,C)-B_{IN}}{E_B(\rho_n,C)\left[\frac{C}{\rho_n} -1+E_B(\rho_n,C)\right]}, \tag{28}$$

where

$$\rho_0 = \begin{cases} \frac{C}{10} & C\leq 2 \\ C-2 & C>2. \end{cases}$$

Using this procedure requires a few (five or six) iterations; for this example ρ_{IN} =35 erlangs or 1260 CCS of IN traffic.

In order to determine the OUT load, ρ_{OUT}, the same sort of iterative procedure is used, except Erlang Loss System is not used as a model. We have developed a mathematical performance model for the system shown in Figure 1, where ρ_{IN}, ρ_{OUT}, C_1 and C_2 are known. It's complete description was given in [7], but it is also given in Appendix A of this Technical Note for

convenience. That model does not assume the blockings the IN and OUT traffic sees on the two-way lines are equal. Let $f(\rho_{IN}, \rho_{OUT}, C_1, C_2)$ be the blocking the IN traffic would see on the two-way lines; for the example under consideration we want to solve the following nonlinear equation:

$$f(35, \rho_{OUT}, 23, 41) = 147/282 = .52 \tag{29}$$

We use a secant iteration scheme [6] to solve this equation; the iterative formula is

$$\rho_{n+1} = \rho_n - \frac{(f(35,\rho_n,23,41)-.52)\,(\rho_n-\rho_{n-1})}{(f(35,\rho_n,23,41) - f(35,\rho_{n-1},23,41))} \tag{30}$$

where ρ is initialized as

$$\rho_1 = 80.2 - 35\ (.383) = 66.8$$

and $\rho_0 = 66.79$.

The factor 80.2 is the solution of the equation $E_B(\rho,\ 41) = .52$, and so the initialization calculation is to find the combined load that gives a .52 blocking on 41 channels via Erlang's Loss Formula and then subtract off from this the amount of traffic that is IN only.

The general problem is to find ρ_{OUT} such that

$$f(\rho_{IN}, \rho_{OUT}, C_1, C_2) = B_{OUT} \tag{31}$$

where ρ_{IN}, C_1, C_2, and B_{OUT} are known. The resulting iteration scheme is

$$\rho_{n+1} = \rho_n - \frac{(f(\rho_{IN},\rho_n,C_1,C_2) - B_{OUT})(\rho_n - \rho_{n-1})}{(f(\rho_{IN},\rho_n,C_1,C_2) - f(\rho_{IN},\rho_{n-1},C_1,C_2))} \tag{32}$$

where

$$\rho_1 = \min\,(.01,\ \hat{\rho} - \rho_{IN}\, B_{IN})$$

and $\rho_0 = \rho_1 - .01$

with $E_3(\hat{\rho}, C_2) = B_{OUT}$. For the example under consideration, $\rho_{OUT} = 63.44$ erlangs or 2284 CCS of OUT traffic.

2. RETRY ADJUSTMENT

We use the same retry adjustment as in the DCA method ,except that when determining the carried IN and OUT loads our performance model is used to determine the INGOS and OUTGOS. If PB_1 and PB_2 are the INGOS and OUTGOS from the model, then

$$\begin{aligned} \text{IN offered load} &= K_1\, \rho_{IN}\, (1 - .65\, PB_1) \\ \text{OUT offered load} &= K_2\, \rho_{OUT}\, (1 - .55\, PB_2) \end{aligned} \tag{33}$$

where K_1 and K_2 are determined from Table I. For the example under consideration we get

$$\begin{aligned} \text{IN offered load} &= 1097 \text{ CCS} = 30.47 \text{ Erlangs} \\ \text{OUT offered load} &= 1790 \text{ CCS} = 49.71 \text{ Erlangs.} \end{aligned} \tag{34}$$

3. SIZING

The DCEC sizing method is different than either DCA's or AT&T's in that it minimizes the total number of channels required. Their methods are just based on sizing the IN line and OUT lines to specific levels of blocking, without regard to total number of channels required. The DCEC method finds the minimum number of both IN and two-way lines that will result in the desired INGOS and OUTGOS (i.e., .05 and .1). From the combinations of IN and two-way lines that will accomplish this, the DCEC method selects the pair that maximizes the carried IN traffic.

The procedure is iterative; at each iteration the number of IN lines is increased by one and the number of two-way lines required to give a .05 INGOS and P.10 OUTGOS is found by using the mathematical performance model discussed earlier and described in Appendix A. For this particular pair of lines, the total number of channels is checked against the current optimal configuration; if less, this configuration replaces the current optimal one. If the total

numbers of lines are equal, then the carried IN load for the latest configuration is checked against the carried IN load for the current optimal configuration. If the current configuration is greater than the current optimal configuration then the it becomes the optimal one and the procedure goes to the next iteration. If it is equal to or less than the optimal configuration the current optimal configuration is left unchanged. If the latest configuration total number of lines is greater than the current optimal configuration, the method goes to the next iteration.

Since the mathematical performance model gives different blocking for the IN and OUT traffic on the two-way lines, this method does not have the same inadequacies as the DCA and AT&T sizing steps. For the example under consideration, $C_1^* = 22$ and $C_2^* = 60$. As one can see the DCEC method does not have any of the problems that the DCA and AT&T's methods have. Table V summarizes the results of all three methods. From this table one sees that the DCEC and DCA methods are in close agreement.

IV. COMPARISONS OF THE ALE METHODS

In this section, we numerically compare the three ALE methods discussed in section III. Two comparisons are presented. The first compares the methods in terms of the load determination step. The second comparison investigates the different sizing philosophies and determines the effect that assuming equal blocking on the two-way trunk has on sizing.

For the comparison of the load determination steps of all these methods, 12 access areas were selected. These areas can be classified as either small, medium or large in terms of the number of lines each contains. From the peg count information, the IN and OUT loads were determined as in the load determination step of each method. These unadjusted loads were then run through an event by event simulation model to see which one agreed most closely with the actual information given by the peg counts. The results of that comparison are given in Tables VI, VII, and VIII. For each of the 12 areas

TABLE V. SUMMARY OF ALL THREE ALE METHODS

STEP		DCA	AT&T	DCEC
Load	IN	1346 CCS	1095 CCS	1260 CCS
Determination	OUT	2281 CCS	1513 CCS	2284 CCS
Retry	IN	1171 CCS	1049 CCS	1097 CCS
Adjustment To Load	OUT	1727 CCS	1450 CCS	1790 CCS
Sizing	C_1^*	17	26	22
	C_2^*	66	48	60

TABLE VI COMPARISONS OF LOAD DETERMINATION STEP FOR SMALL ACCESS AREAS

LOCATION	LOADS ρ_1	ρ_2	BLOCKING ON IN CHANNEL SIM.	PEG COUNT	IN BLOCKING ON 2-WAY SIM.	PEG COUNT	TOTAL IN BLOCKING SIM.	PEG COUNT	% ABS ERROR IN TOTAL IN BLOCKING
AT&T Savana Army Depot	2.06	2.56	.41		.30		.13		58
DCA $C_1=2$, $C_2=4$	2.81	4.17	.51	.57	.48	.54	.25	.31	19
DCEC	3.43	4.87	.57		.55		.31		0
Camp Mabry	5.97	3.33	.72		.31		.22		31
$C_1=2$, $C_2=7$	5.69	5.75	.70	.71	.42	.45	.29	.32	9
	5.75	6.46	.71		.45		.32		0
Radford	1.47	1.81	.31		.17		.05		38
$C_1=2$, $C_2=4$	1.69	2.00	.34	.32	.21	.25	.07	.08	13
	1.55	2.53	.32		.25		.08		0
McAlester	3.06	3.06	.54		.30		.16		43
$C_1=2$, $C_2=5$	3.17	8.50	.54	.44	.60	.63	.32	.28	14
	2.27	10.64	.44		.63		.28		0

TABLE VII COMPARISONS OF LOAD DETERMINATION STEP FOR MEDIUM ACCESS AREA

LOCATION	LOADS ρ_1	ρ_2	BLOCKING ON IN CHANNEL SIM.	PEG COUNT	IN BLOCKING ON 2-WAY SIM.	PEG COUNT	TOTAL IN BLOCKING SIM.	PEG COUNT	% ABS ERROR IN TOTAL IN BLOCKING
AT&T Lexington Army	5.56	10.56	.05		.15		.01		80
DCA C_1=9, C_2=13	7.36	12.53	.14	.16	.28	.32	.04	.05	20
DCEC	7.75	12.78	.16		.30		.05		0
Yuma	5.06	6.97	.29		.20		.06		65
C_1=5, C_2=10	5.16	13.08	.30	.35	.45	.49	.14	.17	18
	15.85	14.17	.35		.50		.17		0
K. I. Sawyer	4.44	10.42	.49		.09		.05		38
C_1=3, C_2=16	5.61	10.08	.57	.60	.11	.13	.06	.08	25
	6.19	9.95	.60		.12		.07		13
Holloman	12.17	22.58	.43		.32		.14		50
C_1=8, C_2=22	16.28	30.80	.55	.57	.50	.49	.27	.28	4
	17.06	29.44	.57		.49		.28		0
Mather	12.78	19.17	.39		.34		.13		46
C_1=9, C_2=19	18.33	17.92	.55	.65	.41	.37	.22	.24	8
	24.29	10.79	.65		.37		.24		0

TABLE VIII. COMPARISONS OF LOAD DETERMINATION STEP FOR LARGE ACCESS AREAS

LOCATION	LOADS ρ_1	ρ_2	BLOCKING ON IN CHANNEL SIM.	PEG COUNT	IN BLOCKING ON 2-WAY SIM.	PEG COUNT	TOTAL IN BLOCKING SIM.	PEG COUNT	% ABS ERROR IN TOTAL IN BLOCKING
AT&T Presidio (S.F.)	34.4	23.6	.21		.07		.02		100
DCA $C_1=30$, $C_2=38$	27.83	32.75	.09	.09	.15	.11	.01	.01	0
DCEC	27.51	30.3	.09		.11		.01		0
Fort Campbell	14.8	18.1	.17		.16		.03		40
$C_1=15$, $C_2=23$	14.0	26.0	.15	.17	.33	.31	.05	.05	0
	14.68	23.43	.17		.28		.05		0
Fort Bragg	30.43	42.03	.30		.31		.09		55
$C_1=12$, $C_2=41$	37.39	63.33	.41	.38	.54	.52	.22	.20	10
	34.80	63.58	.38		.53		.20		0

the loads column are the results one would get by using each method on the peg count information available for that location. The quantities ρ_1 and ρ_2 are the IN and OUT loads expressed in erlangs for the AT&T, DCA and DCEC methods. The next three columns give the results of the simulation and the peg counts for the blocking on the IN only lines, the IN blocking on the two-way lines, and the total IN blocking. The final column is the absolute percent error in total IN blocking.

In all but one case (Presidio), the total IN blocking that results from using the AT&T loads is significantly lower than what the blocking via the peg counts would indicate. This result is in line with our comments concerning their load determination step. They used an improper system for a model of the flow of traffic in the access area. This fact, we felt, would result in predicting lower offered load. As one can see from Tables V, VI, and VII, this is indeed true.

Except for Yuma and Mather, the DCA and DCEC methods were in rather close agreement, with the DCEC method giving results closer to the peg count. The DCA method seems to do better on large trunk groups than it does on smaller ones. From these tables, we also see that the DCEC method is the best for the load determination step, and is quite accurate. Since it was the only method that used different blocking for the IN and OUT traffic on the two-way lines, we feel that consideration of the different blocking on the two-way is vital in the load determination step.

The next problem we considered was determining what effect the imbalance in blocking on the two-way lines has on system sizing. For this study, we assumed the desired INGOS (PB_1^*) and OUTGOS (PB_2^*) were .05 and .1. Four sizing philosophies were considered and are shown on Table IX. The first

three represent a philosophy of minimizing total channels, minimizing total channels and maximizing carried load, and minimizing total channels and then maximizing carried IN load. The final column represents DCA's philosophy of sizing IN lines to .05/.1 = .5 and two-way lines to .1. The AT&T sizing philosophy was not considered because it appeared to us to give a .02 INGOS and a .1 OUTGOS. The loads that were used were determined by the DCEC method except that the OUT load, ρ_2, was not increased by 6%. For each of the sizing philosophies, three results are given: the line sizing when the blocking of the IN traffic is not assumed to be equal to that of the OUT traffic, the sizing when they are assumed to be equal, and the resultant INGOS (PB_1^*) and OUTGOS (PB_2^*) using the sizing given by the equal blocking column.

From Table IX the impact on system sizing of the imbalance in blocking seems greatest in the larger access areas. For the DCA's sizing philosophy, it seems to have the least impact. For the DCEC's sizing philosophy, it appears to result in different configurations in several of the larger access areas, with the result of usually requiring more IN only lines. In some cases, the equal blocking required less total channels than the unequal blocking (i.e., Camp Mabry), but even in those cases the resultant INGOS (PB_1^*) is greater than the desired .05. As a result of this table, we feel that the impact of assuming equal blocking on the two-way lines is not as critical as in the load determination step, but when used, results in less IN only lines.

Table IX investigates the imbalance in blocking for OUTGOS's of .1, .2, .3 and .4. In addition to the results noted for Table VIII the main result seen in Table IX is related to the fewer IN lines required for equal

blocking. As the OUTGOS is increased, this result is not as great. Therefore, as the OUTGOS is increased, the resultant system sizings, assuming equal blocking or not, tend to become the same.

In summary, we feel that assuming equal blocking of the IN and OUT traffic on the two-way line is critical in the load determination step and does affect the system sizing for larger access areas when the desired OUTGOS is around .1.

Table IX. EFFECTS OF THE IMBALANCE IN BLOCKING ON THE TWO-WAY LINES FOR VARIOUS SIZING PHILOSOPHIES

LOCATION ρ_1 ρ_2		MIN. TOTAL CHLS.			MIN. TOTAL CHLS. THEN MAX. CARRIED LOAD			MIN. TOTAL CHLS. THEN MAX. IN CARRIED LOAD			SIZE IN TO .5		
		≠BLKG	=BLKG	PB_1 PB_2	≠BLKG	=BLKG	PB_1 PB_2	≠BLKG	=BLKG	PB_1 PB_2	≠BLKG	=BLKG	PB_1 PB_2
Savanna	C_1	3	3	.038	0	1	.048	3	3	.038	2	2	.044
2.74 3.43	C_2	7	7	.083	10	9	.056	7	7	.083	8	8	.066
Camp Mabry	C_1	5	3	.060	0	3	.060	5	3	.060	3	3	.060
4.55 4.94	C_2	9	10	.088	14	10	.088	9	10	.088	11	10	.088
Radford	C_1	2	2	.035	0	0	.049	2	2	.035	2	2	.035
1.47 2.24	C_2	5	5	.086	7	7	.049	5	5	.086	5	5	.086
Mc Alester	C_1	3	3	.024	1	1	.044	3	3	.024	2	2	.035
1.35 7.04	C_2	10	10	.095	12	12	.059	10	10	.095	11	11	.072
Lexington	C_1	7	6	.046	5	3	.044	7	6	.046	5	5	.050
7.49 11.18	C_2	16	17	.084	13	20	.068	16	17	.084	18	18	.077
Yuma	C_1	5	5	.042	4	3	.053	5	5	.042	4	4	.048
5.20 10.71	C_2	15	15	.094	15	17	.075	15	15	.094	15	16	.083
K.I. Sawyer	C_1	7	4	.057	0	4	.057	7	4	.057	4	4	.057
5.83 9.38	C_2	13	15	.089	20	15	.089	13	15	.089	16	15	.089
Presidio	C_1	21	17	.053	19	15	.054	21	17	.053	15	15	.054
27.33 29.38	C_2	39	43	.089	41	45	.085	39	43	.089	46	45	.086
Ft.Campbell	C_1	12	11	.046	9	6	.055	12	11	.046	8	8	.052
14.17 20.70	C_2	27	28	.091	30	33	.075	27	28	.091	32	31	.080
Ft. Bragg	C_1	21	18	.051	13	15	.054	21	18	.051	15	16	.053
30.32 47.01	C_2	58	61	.094	61	54	.090	58	61	.094	54	63	.091
Holloman	C_1	12	10	.047	9	6	.055	12	10	.047	8	8	.052
13.97 21.98	C_2	28	30	.088	31	34	.076	28	30	.088	33	32	.081
Mather	C_1	17	12	.053	15	12	.053	17	12	.053	11	11	.054
20.49 8.79	C_2	17	22	.074	19	22	.074	17	22	.074	24	23	.072

TABLE X. EFFECTS OF THE IMBALANCE IN BLOCKING ON THE TWO-WAY LINES FOR VARIOUS OUTGOS

LOCATION		$PB_1^*=.05$ $PB_2^*=.10$			$PB_1^*=.05$ $PB_2^*=.20$			$PB_1^*=.05$ $PB_2^*=.30$			$PB_1^*=.05$ $PB_2^*=.40$		
ρ_1 ρ_2		≠BLKG	=BLKG	PB_1 PB_2	≠BLKG	=BLKG	PB_1 PB_2	≠BLKG	=BLKG	PB_1 PB_2	≠BLKG	=BLKG	PB_1 PB_2
Savanna	C_1	3	3	.038	4	3	.061	5	5	.031	5	5	.031
2.74 3.48	C_2	7	7	.083	5	6	.144	4	4	.284	4	4	.284
Camp Mabry	C_1	5	3	.060	6	7	.039	8	6	.052	7	7	.037
4.55 4.94	C_2	9	10	.088	7	7	.163	5	6	.240	5	5	.312
Radford	C_1	2	2	.035	3	3	.024	3	3	.041	3	3	.041
1.47 2.24	C_2	5	5	.086	4	4	.143	3	3	.273	3	3	.273
Mc Alester	C_1	3	3	.024	3	4	.019	4	4	.025	4	4	.031
1.85 7.94	C_2	10	10	.095	8	8	.189	7	7	.260	6	6	.343
Lexington	C_1	7	6	.046	10	8	.055	10	9	.052	10	10	.044
7.49 11.18	C_2	16	17	.084	22	13	.180	10	11	.257	9	9	.356
Yuma	C_1	5	5	.042	7	6	.054	7	7	.047	8	8	.036
5.20 10.71	C_2	15	15	.094	12	12	.189	10	10	.276	8	8	.387
K.I. Sawyer	C_1	7	4	.057	7	7	.047	8	8	.042	9	8	.049
5.88 9.38	C_2	13	15	.089	11	11	.180	9	9	.274	7	8	.339
Presidio	C_1	21	17	.053	28	24	.063	30	27	.062	31	29	.056
27.23 29.38	C_2	39	43	.089	29	32	.178	24	26	.273	20	21	.383
Ft.Campbell	C_1	12	11	.046	15	14	.054	16	16	.047	17	16	.059
14.17 20.70	C_2	27	28	.091	21	22	.183	18	18	.280	15	15	.385
Ft. Bragg	C_1	21	18	.051	30	26	.059	32	29	.061	33	31	.059
30.32 47.01	C_2	58	61	.094	44	47	.188	37	39	.284	3[illegible]	32	.391
Holloman	C_1	12	10	.047	15	14	.051	17	15	.058	18	16	.054
13.97 21.98	C_2	28	30	.088	22	23	.182	18	19	.286	15	16	.376
Mather	C_1	17	12	.053	21	19	.054	23	22	.053	25	23	.053
20.49 8.79	C_2	17	22	.054	12	14	.146	9	10	.256	7	8	.356

V. CONCLUSIONS

The two current ALE methods used to engineer the AUTOVON access area are described and the weaknesses in both methods pointed out. A new method developed at DCEC was then presented and compared with the other two methods. The AT&T method always seemed to underestimate the offered loads whereas the DCA and DCEC methods seemed to be in closer agreement, with the DCEC method slightly more accurate.

Both the AT&T and DCA methods rely heavily on the use of existing tables. The DCEC method relies on the use of a computer. Of course, we could develop a set of tables as in the AT&T and DCA method, but if a computer is available the CPU time on any reasonably sized machine to do one complete ALE job on a given access is less than 1 second, even for a large size access area.

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APPENDIX A

MATHEMATICAL MODEL FOR ACCESS LINE PERFORMANCE

Consider the access line configuration as shown in Figure 1. If ρ_1 is the inward load in erlangs and ρ_2 the outward load in erlangs, we now give a mathematical model that will predict the performance in the access areas. In what follows, $E_B(\rho,C)$ is Erlang's Loss Formula (Erlang B).

We use Erlang's Loss Formula to represent the blocking on the IN only lines (C_1); therefore this blocking probability is:

$$E_B(\rho_1,C_1) = \frac{\dfrac{\rho_1^{C_1}}{C_1!}}{\sum_{r=0}^{C_1} \dfrac{\rho_1^r}{r!}} . \tag{A.1}$$

Next, we can find the mean (α) and variance (ν) of the overflow process from C_1 [3], as

$$\alpha = \rho_1 E_B(\rho_1,C_1) \tag{A.2}$$

$$\nu = \alpha(1-\alpha+\rho_1/(C_1+1+\alpha-\rho_1)). \tag{A.3}$$

The mean (β) and variance (ν_2) of the offered load to the two way trunk (C_2) is given by

$$\beta = \alpha + \rho_2 \tag{A.4}$$

$$\nu_2 = \nu + \rho_2 \tag{A.5}$$

with a peakedness factor, z,

$$z = \nu_2/\beta. \tag{A.6}$$

The behavior on the two-way trunk group can be analyzed by using Wilkinson's Equivalent Random Technique (see Cooper [3]). First, we compute an equivalent random load, A, to be first offered to S trunks and then overflowed to the ν_2 trunk group, such that the mean and variance of this overflow process equal β and ν_2. The values of A and S are

$$A = \nu_2 + 3z(z-1) \tag{A.7}$$

$$S = \left[A(\beta+z)/(\beta+z-1)\right] - \beta - 1. \tag{A.8}$$

Since S may not be integer-valued we let

$$NS = [S]; \tag{A.9}$$

that is, NS is the largest integer less than or equal to S. The blocking on the S trunk group is computed as

$$PBB = E_B(A,NS) \quad (A/(NS+1+AE_B(A,NS)))^{(S-NS)}. \tag{A.10}$$

The next step in Wilkinson's Equivalent Random Technique is to find the blocking on the composite C_2+S trunk group. Since this number may not be integer, we set

$$NS_2 = [C_2+S], \tag{A.11}$$

the greatest integer less than or equal to C_2+S, and compute the composite blocking on the C_2+S trunk group as

$$PBB_1 = E_B(A,NS_2)(A/(NS_2+1+AE_B(A,NS_2)))^{(S-NS)}. \tag{A.12}$$

The final step in using Wilkinson's Equivalent Random Technique is to compute the total loss probability on the C_2 trunk group, PL, by

$$PL = PBB_1/PBB. \tag{A.13}$$

The only remaining problem is determination of the loss probabilities that the inward (PB_2(IN)) and outward traffic (PB_2(OUT)) sees on this trunk group. In general, these probabilities are different from PL, with the inwards being higher than PL and the outwards being lower than PL. We have conducted an investigation of this system and, via a regression analysis, have come up with the following expressions for PB_2(IN) and PB_2(OUT);

$$PB_2(IN) = PL(1+\nu/\alpha-z)k) \qquad (A.14)$$

and

$$PB_2(OUT) = PL(1+(1-z)k) \qquad (A.15)$$

where

$$\tau_1 = -.0528\ C_2 z(-4.163) \qquad (A.16)$$

$$\tau_2 = -5.456\ PLz^{(-2.025)} \qquad (A.17)$$

and

$$k = [2.459z^{(-2.82)}]\ \exp\ (\tau_1 + \tau_2). \qquad (A.18)$$

Thus, the blocking that the IN traffic sees on the one-way lines is $E_B(\rho_1, C_1)$ and on the two-way lines, $PB_2(IN)$, with a total blocking, PB_1,

$$PB_1 = E(\rho_1, C_1) PB_2(IN). \qquad (A.19)$$

The blocking the OUT traffic sees on the two-way lines is $PB_2 = PB_2(OUT)$.

The general problem of differentiating between the blockings of various classes of traffic using the same trunk group has been considered in the literature [11], [12], [13] and [14]. In fact, the general form of equations

(A.14) and (A.15) was first found in [8]. The other references have been attempts to make the approximation more accurate. From our experiences our methods are accurate enough for our type of work.

Tables A.1, A.2 and A.3 give some results of the comparison of our mathematical performance model with the results of the event-by-event simulation model. The first comment we can make is that the mathematical model and the simulation model closely agree. There is only one case where a substantial difference in results shows up: Ft. Campbell for the IN blocking and the two-way lines.

TABLE A.1. COMPARISON OF PERFORMANCE FOR SMALL ACCESS AREAS (top entry in box is simulation result, bottom entry mathematical model)

LOCATION (ρ_1, ρ_2) (C_1, C_2)	BLOCKING ON IN LINES	IN BLOCKING ON 2-WAY LINES	OUT BLOCKING ON 2-WAY LINES	TOTAL IN BLOCKING
Savanna	.57	.55	.51	.31
(3.43, 4.87)	.57	.54	.52	.31
(2, 4)				
Camp Mabry	.71	.45	.42	.32
(5.75, 6.46)	.71	.45	.43	.32
(2, 7)				
Radford	.32	.25	.21	.08
(1.55, 2.53)	.32	.25	.21	.08
(2, 4)				
McAlester	.44	.63	.62	.28
(2.27, 10.64)	.44	.63	.62	.28
(2, 5)				

TABLE A.2. COMPARISON OF PERFORMANCE FOR MEDIUM ACCESS AREAS

LOCATION (ρ_1, ρ_2) (C_1, C_2)	BLOCKING ON IN LINES	IN BLOCKING ON 2-WAY LINES	OUT BLOCKING ON 2-WAY LINES	TOTAL IN BLOCKING
Lexington (7.75, 12.78) (9, 13)	.16 / .16	.30 / .32	.22 / .22	.05 / .05
Yuma (5.85, 14.17) (5, 10)	.35 / .35	.50 / .49	.44 / .44	.17 / .17
K. I. Sawyer (6.19, 9.95) (3, 16)	.60 / .60	.12 / .13	.10 / .11	.07 / .08
Holloman (17.06, 29.44) (8, 22)	.57 / .57	.49 / .49	.47 / .46	.28 / .28
Mather (24.29, 10.79) (9, 19)	.65 / .65	.37 / .37	.32 / .33	.24 / .24

TABLE A.3. COMPARISON OF PERFORMANCE FOR LARGE ACCESS AREA

LOCATION (ρ_1, ρ_2) (C_1, C_2)	BLOCKING ON IN LINES	IN BLOCKING ON 2-WAY LINES	OUT BLOCKING ON 2-WAY LINES	TOTAL IN BLOCKING
Presidio	.09	.11	.05	.01
(27.51, 30.30)	.09	.11	.06	.01
(30, 38)				
Ft. Campbell	.17	.28	.21	.05
(14.68, 23.43)	.17	.31	.22	.05
(15, 23)				
Ft. Bragg	.38	.53	.47	.20
(34.80, 63.58)	.38	.52	.47	.20
(23, 41)				

These tables also point up the imbalance in blocking on the two-way lines that the IN and OUT traffic sees. For all 12 cases the IN blocking on the two-way lines is greater than the OUT blocking. As we pointed out earlier, this was caused by the peaked nature of the IN traffic being offered to the two-way lines. In some cases, these differences are rather substantial; consider Presidio in which we have .11 to .05.

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